INDEPENDENT COST ASSESSMENT OF THE COMMERCIAL CREW PROGRAM

INDEPENDENT COST ASSESSMENT REPORT

MARCH 1ST, 2013

Booz | Allen | Hamilton

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Task Overview

NASA's Commercial Crew Program (CCP) is facilitating the development of a U.S. commercial crew transportation system (CTS) capability with the goal of achieving safe, reliable and cost-effective access to and from the International Space Station (ISS) and low Earth orbit. CCP demonstrates a new way of doing business in partnership with industry which presents both opportunities and challenges for NASA.

NASA engaged Booz Allen Hamilton to conduct an independent cost assessment (ICA)[1] of the government cost estimates of the respective Commercial Crew Integrated Capability (CCiCap) Partner designs and schedules and of Commercial Crew Program's cost and schedule plans. The government cost estimates represent the total amount "to-go" from end of CCDev 2 through certification and include partner contributions for Boeing, Sierra Nevada Corporation (SNC), and SpaceX. Based on insights gained as a result of these assessments, recommendations regarding data needs and estimating approaches for cost and price analysis to support future service acquisition planning and analysis are also provided.

Key Findings

Overall, the CCP government cost estimates are of high quality and follow standard cost estimating best practices but should be considered optimistic (e.g., likely to experience cost growth). It should be noted that CCP's unique public-private partnership aims to allow any realized cost growth to be shared between the government and the providers. CCP is also taking a holistic approach to planning for and minimizing cost and schedule growth through methods such as lowering the impact of risks through mitigation strategies, planning for risks by incorporating them into the government cost estimates, protecting against the risks by allocating unallocated future expense (UFE) against their impacts, and providing business incentives for providers to minimize cost growth or use their own funding to pay for cost growth during the Phase 2 Certification Contract (P2CC).

Finding #1: The government cost estimates for each provider used an acceptable and consistent estimating methodology across each of the estimates and applied the estimating methodology correctly. The majority of the estimates are documented to a level of detail where any qualified cost estimator could reproduce them from scratch if provided the same datasets. A consistent estimating methodology was used across the three government cost estimates which is a best practice.

Recommendation #1: CCP's cost estimating team should continue its best practice of using the same estimating methodology across the providers while continuing to research new ways to more accurately predict costs. This research may result in new estimating methodologies. Where these new

[1] An ICA is defined as an outside, non-advocate's evaluation of a cost estimate's quality and accuracy looking specifically at a program's technical approach, risk, and acquisition strategy to ensure that the program's cost estimate captures all requirements.

methodologies result in significant cost changes from the initial estimate, CCP should perform a root-cause analysis to determine the cause of the delta. When appropriate, CCP should extend the new estimating methodologies across all three estimates to ensure consistency.[2]

Finding #2: The government cost estimates use the appropriate estimating methodology (analogy, parametric, build-up, or extrapolation from actuals), and are of the appropriate level of detail, for a program in the design phase. The majority of the estimates are parametric or analogy. Typically detailed engineering build-up estimates are not as common at this stage of the life cycle.

Recommendation #2: CCP's cost estimating team should develop an approach to validate their estimates using the extrapolation from actuals methodology to improve the accuracy and credibility of the estimates.

Finding #3: The CCP cost estimating team developed high quality cost estimates despite encountering two challenges. Estimating "new ways of doing business" encouraged by CCP's alternative acquisition strategy has very limited historical precedence within NASA. Additionally, lack of cost data due to limited provider financial reporting requirements reduced CCP estimating team's ability to validate their cost estimates against high-fidelity sunk-cost data.

Recommendation #3: CCP's cost estimating team should continue their practice of incorporating new data from the providers or other sources into their estimates in a timely manner. CCP should continue to evaluate the cost benefit tradeoff of acquiring additional data from the providers to improve the accuracy and credibility of the existing cost estimates over time.

Finding #4: NASA / Air Force Cost Model (NAFCOM) is an acceptable model for estimating hardware development costs. There is limited information to inform how best to calibrate NAFCOM or adjust estimates extracted from NAFCOM to account for "new ways of doing business".

Recommendation #4: CCP's cost estimating team should perform additional research with respect to the best ways to account for "new ways of doing business" in their cost estimates.

[2] GAO Cost Estimating and Assessment Guide – Best Practices for Developing and Managing Capital Program Costs (GAO-09-3SP).

Finding #5: The government's cost estimates for each provider are based on optimistic ground rules and assumptions resulting in cost estimates that are optimistic. Cost risk and uncertainty analysis conducted on the cost estimates excludes, or underestimates, the potential risk and uncertainty impact of these assumptions when bounding the estimates.

Recommendation #5: CCP's cost estimating team should work to bound cost and schedule risks associated with these assumptions and incorporate them into each of the three provider estimates.

Finding #6: No government duration estimate exists for any provider. CCP is currently relying on the accuracy of the provider-defined milestones. The absence of a government duration estimate for each provider makes it difficult to ensure the government cost estimates align to a schedule and reduces CCP's ability to independently evaluate the providers' milestones and associated schedule artifacts, where available.

Recommendation #6: CCP should transition to a more robust parametric cost model with integrated schedule capabilities.

Finding #7: CCP performed a budget exercise linking the government cost estimates to their program's budget plan to analyze program funding strategies consisting of single and multiple providers, displaying a best practice of incorporating cost estimates into budget planning exercises.

Recommendation #7: CCP should continue to link cost estimates and available budget to program funding analysis and keep their budgetary exercise up-to-date by incorporating latest estimating, budgetary, and risk data as they become available.

Finding #8: The ICA team analyzed the optimistic ground rules and assumptions (see Finding #5) and identified additional risk to government cost estimates. Risks identified in analysis include mass/new design NAFCOM input optimism, systems integration cost estimate optimism, the assumption in CCP estimates that providers will defer profit from development contracts until the services contract, and discrete risks identified by ICA technical team.

Recommendation #8: CCP should develop positions on additional risks identified and take action to incorporate them into their program strategy. Where non-monetary actions cannot mitigate the risk, the program should ensure funds or UFE exist to cover the potential impact of these assumptions.

Finding #9: CCP continues to address budget challenges impacting crew transportation service acquisition. CCP monitors its budget relative to cost through the program's budget plan process and conducts rigorous budget exercises to inform the program's acquisition strategy.

Recommendation #9: CCP should continue to incorporate their financial and affordability constraints into the program's acquisition strategy to enhance the likelihood that at least one provider is successful.

Finding #10: UFE levels established in program managers review (PMR) are not based on a quantified analysis of program risk and uncertainty.

Recommendation #10: CCP should use an accepted cost-risk analysis methodology to analyze and inform UFE levels in future budget planning. Analysis should account for uncertainty in government cost estimates and program risks that could impact government cost estimates. This analysis should be time-phased to ensure UFE is available when needed.

Finding #11: In both the CCP and ICA Budget Exercises, projected annual appropriations levels are below yearly phased cost estimates. Providers will be expected to fund the gap in their P2CC plans.

Recommendation #11: CCP should communicate their anticipated year-to-year budget constraints to the providers to allow them to adequately plan for this constraint in their P2CC proposals.

Additional Agency-level findings and recommendations, not specific to CCP, were also generated as a result of the partner-focused and program-focused assessments. These findings and recommendations can be found in Section III of this report.

I. Introduction

NASA's Commercial Crew Program is leading the development of a U.S. commercial crew transportation system capability for safe, reliable and cost-effective access to and from the International Space Station and low Earth orbit. CCP demonstrates a new way of doing business in partnership with industry which presents both opportunities and challenges for NASA.

CCP Goals and Objectives[3]

Program Goals

- Facilitate U.S. private industry development of safe, reliable, and cost effective human space transportation to and from low Earth orbit and the International Space Station for use by the U.S. Government and other customers by mid calendar year 2017
- Enable the eventual purchase by NASA of commercial services to meet its ISS crew transportation needs, once the capability is matured and available

Program Objectives

- Mature the design, development, demonstration, and certification of U.S. commercial crew space transportation capabilities
- Prepare for transition to a services phase – ensure, through development and demonstration, that the crew transportation capability is safe, reliable, and is an efficient method for transportation to the ISS and low Earth orbit
- Develop, award, and execute milestone-based instruments that support the development, testing, and demonstration of multiple commercial crew systems
- Provide the technical assurance to support certification of commercial space transportation system(s)
- Provide Commercial Partners access to NASA's technical expertise and resources for the resolution of development issues
- Develop and implement a strategy that stimulates the U.S. space transportation industry, encourages the availability of human space transportation services to NASA and other customers, and addresses the needs of industry partners to the greatest extent possible
- Develop, maintain, and implement streamlined and effective Program processes
- Continually improve critical knowledge and skill capabilities

[3] Goals and objectives from CCP Program Plan Version 6.0

NASA engaged Booz Allen Hamilton to perform independent assessments of cost estimates (hereafter referred to as Independent Cost Assessments, or ICAs) developed by the Commercial Crew Program of the respective Commercial Crew Integrated Capability (CCiCap) provider designs and schedules (partner-focused assessment), and to assess the sufficiency of reserves contained in the estimates (program-focused assessment). The providers include Boeing, Sierra Nevada Corporation (SNC), and SpaceX. Based on insights gained as a result of these assessments, recommendations regarding data needs and estimating approaches for cost and price analysis to support future service acquisition planning and analysis are also provided.

The approach employed by the ICA team was designed to address the definitional standard of an ICA. According to the Government Accountability Office (GAO) Cost Estimation and Assessment Guide (U.S. Government Accountability Office, 2009):

> *"An ICA is an outside, non-advocate's evaluation of a cost estimate's quality and accuracy, looking specifically at a program's technical approach, risk, and acquisition strategy to ensure that the program's cost estimate captures all requirements.*
>
> *Typically requested by a program manager or outside source, it may be used to determine whether the cost estimate reflects the program of record. It is not as formal as an [Independent Cost Estimate] and does not have to be performed by an organization independent of the acquisition chain of command, although it usually is."*[4]

It is important to reiterate the distinction between an ICA and an Independent Cost Estimate (ICE). An ICE is a new estimate, whereas an ICA assesses the quality of an existing estimate. For this assessment, the ICA team focused the assessment on Basis of Estimates (BOEs) prepared by the CCP cost estimating team and provided an independent, unbiased assessment of these government estimates. The methodology and process used by Booz Allen are described in this report, with additional methodology detail in the Appendix A.

[4] GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs. GAO-09-3SP. March 2009

II. Independent Cost Assessment

The Booz Allen ICA team (ICA team) performed independent assessments of cost and schedule estimates prepared by the CCP Program Office and of CCP's budget and schedule plans. The assessment was conducted from October 2012 through February 2013. The ICA team was provided with a variety of data to help facilitate evaluation of the provider estimates. The data provided the ICA team with an overview of CCP and proposed provider status and design solutions.

Data Provided to ICA Team

Risk, cost, schedule and technical design data were used to provide necessary detail for completion of the cost assessments. A significant portion of data assessed was contained in milestone review documentation and program budget exercise documentation. Examples of review documentation provided include system and design data from Conceptual Design Review, Concept Baseline Review, Preliminary Design Review, Integrated Systems Review, and Design Status Review documents from all three providers. CCiCap space act agreement details were also evaluated.

ICA Approach

The ICA team implemented the approach shown in Figure 1 to conduct the independent cost assessment of provider cost and schedule estimates and program budget and schedule plans.

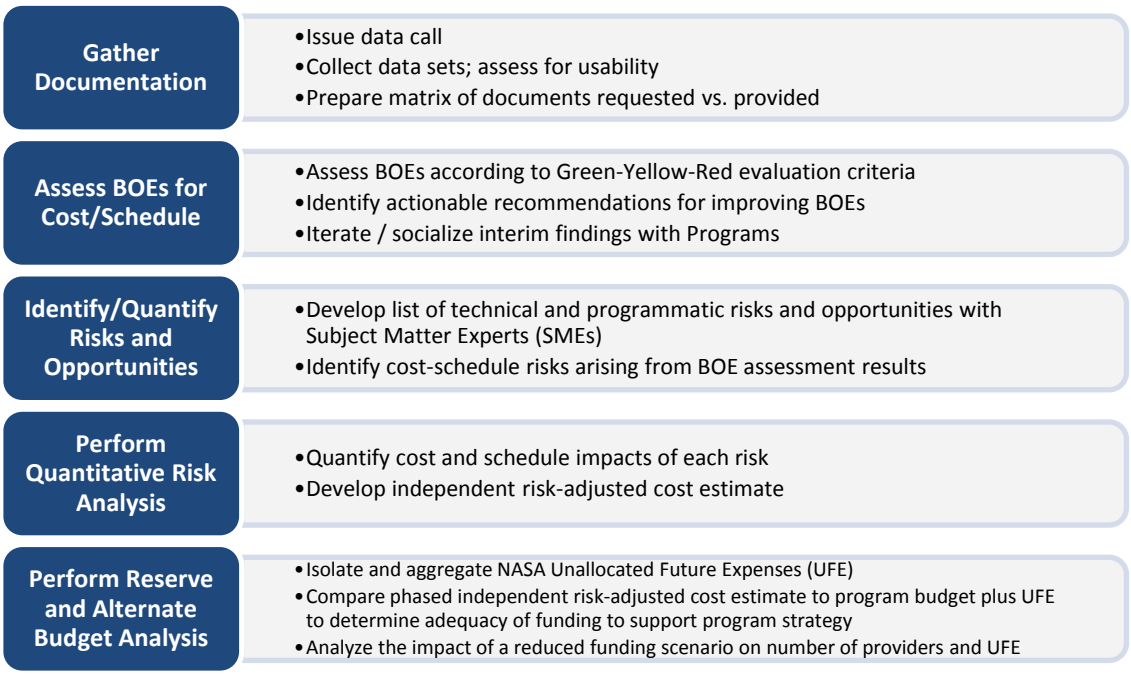

Figure 1: ICA Assessment Approach

The ICA team assessed the provider estimates in two ways for the partner-focused assessment. The first assessment encompassed a detailed review of the BOE. A BOE is documentation that describes the justification and rationale for a cost estimate. Traditionally, BOEs are provided as discrete

documentation for each individual cost estimate at the level the estimate was produced. The second, summary assessment focused on a evaluating the overall estimate based on the GAO characteristics of a high-quality, reliable cost estimate. The summary assessment builds on the estimate level BOE review and characterizes the overall estimate using GAO's four properties of quality cost estimates (U.S. Government Accountability Office, 2009).

The ICA team assessed CCP's budget and schedule plans in two phases for the program-focused assessment. The first phase identified and quantified risks the ICA team identified within the program's cost estimate. During the second phase, these risks were applied to the CCP cost estimates and the resulting values compared to the program's available funds under multiple budget scenarios. Analysis included assumptions and UFE sizing to accomplish the program acquisition and certification strategy.

Basis of Estimate Assessment

Approach

The ICA team focused on BOEs used by CCP to generate their cost and schedule estimates. The underlying concept is that a poorly documented basis of estimate introduces risk and an estimator would be obliged to adjust the estimate by applying reserves against that risk. Well justified BOEs can negate or reduce that risk, allowing reserves to be deployed to more meaningful mitigation targets.

Detailed Assessment Rating Criteria

For the detailed assessment, the BOE was evaluated using a green-yellow-red rating at the level at which the estimate was created. Figure 2 describes the criteria associated with the green-yellow-red rating used to assess each portion of an estimate. When conducting the detailed BOE assessment, the evaluation was dependent on estimating methodology (e.g. a parametric estimate will have a different set of criteria than a buildup estimate – see Appendix A for a description of criteria by estimating methodology). Optimism or conservatism of the ground rules and assumptions was not assessed. Based on the detailed BOE assessment, the ICA team recommended improvements to the estimates where appropriate.

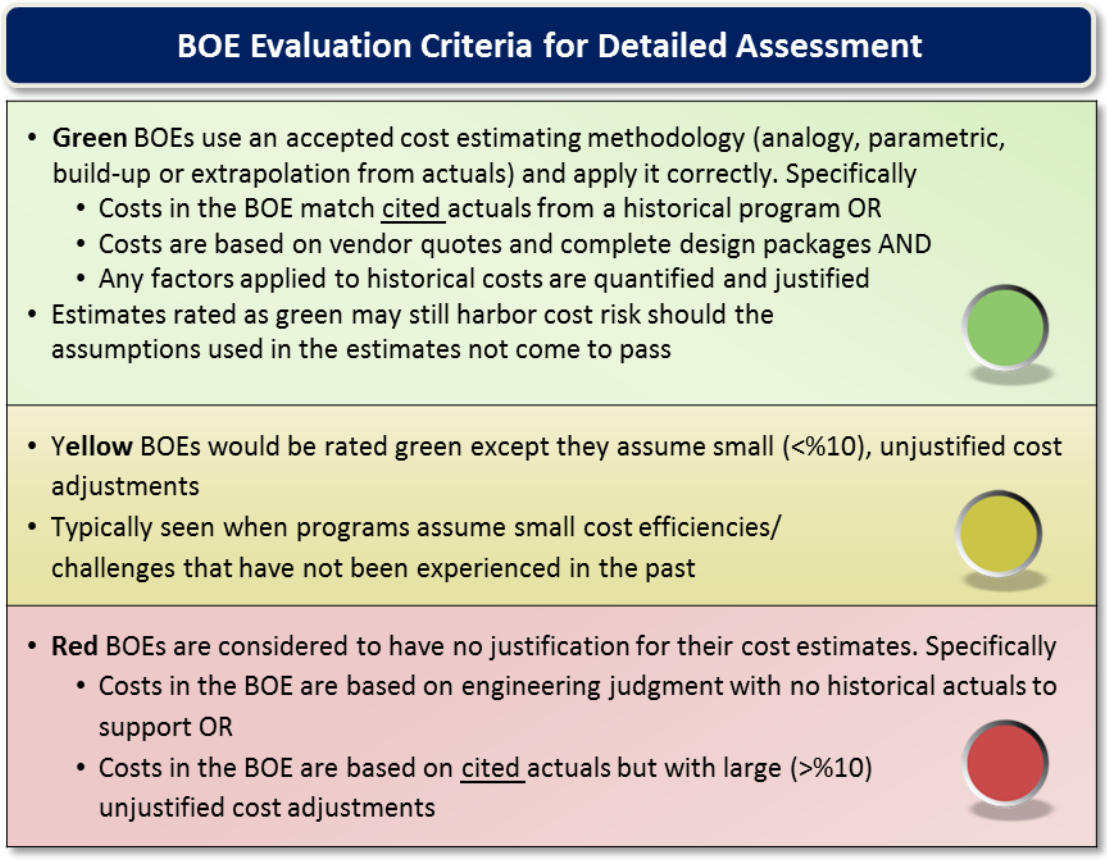

Figure 2: BOE Rating Criteria

Consistent with the scope issued by NASA, the ICA team focused on assessing the quality of each BOE on an individual basis.

Summary Assessment Criteria

In addition to conducting a Red/Yellow/Green assessment of the BOE for each cost element, the ICA team recognized that summary-level observations could subsequently be provided for CCP. For the summary assessment, the estimates were evaluated using a Harvey-Ball rating system to show how well the estimates meet the GAO's four characteristics of a high-quality, reliable estimate. Unlike the detailed assessment, the summary assessment does evaluate the optimism or conservatism of the ground rules and assumptions used to develop the estimate. Based on the summary assessment, the ICA team recommended improvements to the estimates where appropriate. To facilitate the characterization of such observations, the team referenced the GAO's (U.S. Government Accountability Office, 2009) four properties of quality cost estimates defined as:

> *Comprehensive:* Comprehensive cost estimates completely define the program, reflect the current schedule, and are technically reasonable. In addition, cost estimates should be structured in sufficient detail to ensure that cost elements are neither omitted nor double-counted. For example, if it is assumed that software will be reused, the estimate should account for all associated costs, such as interface design, modification, integration, testing, and documentation.
>
> *Well Documented:* Cost estimates are considered valid if they are well documented to the point at which they can be easily repeated or updated and can be traced to original sources through auditing. Rigorous documentation also increases an estimate's credibility and helps support an organization's decision making. The documentation should explicitly identify the primary methods, calculations, results, rationales or assumptions, and sources of the data used to generate each cost element.
>
> *Accurate:* Estimates are accurate when they are not overly conservative or too optimistic, based on an assessment of most likely costs, adjusted properly for inflation, and contain few, if any, minor mistakes. In addition, when schedules or other assumptions change, cost estimates should be revised to reflect their current status.
>
> *Credible:* Credible cost estimates clearly identify limitations because of uncertainty or bias surrounding the data or assumptions. Major assumptions should be varied and other outcomes recomputed to determine how sensitive outcomes are to changes in the assumptions. In addition, a risk and uncertainty analysis should be performed to determine the level of risk associated with the estimate. Finally, the results of the estimate should be cross-checked and an ICE performed to determine whether alternative estimate views produce similar results.

For schedule assessment, the ICA team leveraged the NASA Schedule Management Handbook (NASA, 2011) and GAO Best Practices Guide (U.S. Government Accountability Office, 2009) to define the characteristics of a valid and well-founded schedule estimate to be traceable and executable.

Traceable: Schedule estimates are traceable when they are based on well-founded and/or previously accepted schedule information of established programs with comparable scope. Strong estimates will be derived from schedule information developed using industry best practices and standards. Lastly, traceable estimates should include adjustments and justifications for variations from reference material.

Executable: Estimates are executable when they are founded on clearly defined work packages consistent with progress within the program lifecycle. Valid estimates will contain realistic schedule durations based on projected work hours and program deliverables. Executable schedule estimates will also demonstrate reasonable integration with cost estimates and include considerations for programmatic risk.

The narrative structure of the assessments in this report is aligned with these cost and schedule rating criteria. The ICA team used Harvey Balls, defined in Figure 3, to standardize presentation of qualitative program-level observations based on these rating criteria. Evaluation criteria are independent of estimating methodology.

Rating Criteria		
All		All BOEs meet all criteria
Most		Most BOEs meet criteria, or BOEs meet most criteria
Some		Some BOEs meet the criteria, or BOEs meet some of the criteria
Few		Few BOEs meet the criteria, or BOEs meet a few of the criteria
None		No BOEs meet the criteria, or BOEs meet none of the criteria.

Figure 3: Rating Criteria for Summary Assessment

Overview

The ICA team performed a thorough review of all BOEs, information and data the CCP team provided in support of their cost estimates. Overall, the documentation and quality of the estimates met expectations given the program's early lifecycle phase.

Estimating Methods

Table 1 details the key cost elements by provider along with the cost estimating method used for each of the estimates by the CCP cost estimating team. Detailed definitions of the cost estimating methods are located in Appendix A.

Table 1: CCP Estimating Methods

Element of Cost	Boeing	SNC	SpaceX	Risk Method
Launch Vehicle Atlas/ Falcon 9	Parametric using NASA/Air Force Cost Model (NAFCOM)			FRISK (NAFCOM methodology)
Crew Vehicle / Hardware	Parametric using NAFCOM			FRISK (NAFCOM methodology)
Systems Integration	Analogy			None
Ground Systems	Engineering Judgment			Outputs based risk simulation
Mission Systems	Analogy/Engineering Build up			Outputs based risk simulation

Estimate Ground Rules and Assumptions

The CCP cost estimating team articulated their key overarching ground rules and assumptions that were used to develop the three provider estimates in their kick-off briefing to the ICA team. The estimates represented combined NASA and provider costs. Estimates were 'to-go' cost from end of CCDev 2 through certification and first crew launch to ISS. Ground rules included the use of NAFCOM to estimate hardware DDT&E costs. NAFCOM is traditionally used early in design phase (some provider subsystems are beyond Critical Design Review (CDR) level of design maturity). The CCP estimating team rendered an interpretation of NAFCOM's "New Design score" as a proxy for heritage, new technology, and magnitude of work to be completed to account for this.

Cost estimates for Ground Systems were provided by KSC CCP staff. Mission Systems cost estimates were based on deltas to JSC International Space Station estimate provided to CCP estimating team. The estimate incorporates program information through October, 2012.

Analysis

The ICA team conducted an independent cost assessment of the government cost estimates of the respective CCiCap partner designs and schedules. Utilizing the green-yellow-red methodology previously outlined, the ICA team assessed various aspects of the BOEs developed. A series of findings related to methodology employed, quality of estimates, and ground rules and assumptions were generated based on the assessment. Table 2 summarizes the ICA partner-focused assessment results.

Table 2: Summary of ICA Partner-Focused Assessment Results

Cost Estimates		
GAO Criteria	**ICA Rating**	**Rationale**
Well-Documented		The majority of the government cost estimates trace back to the historical data used in their development, include a technical baseline description, and document data normalization steps. The estimates are documented in enough detail that a qualified cost analyst unfamiliar with the program could recreate them quickly with the same result. Exceptions to this across all three providers' estimates include ground and launch operations.
Comprehensive		No cost elements are omitted or double counted within the estimates and all ground rules and assumptions are fully detailed. Each estimate has a WBS and each element is described within a WBS dictionary.
Accurate		The estimates are based on optimistic assumptions for each provider. Computational or methodological errors found within the estimates are minor and have little impact on the accuracy of the estimate.
Credible		The CCP estimating team has performed sensitivity analysis to determine the key cost-drivers for each estimate. The CCP estimates account for risk and uncertainty, yet the risk analysis excludes or underestimates risk arising from optimistic assumptions (i.e., design changes, mass growth, and commercial ways of doing business). The CCP estimating team has developed cross-checks to further support their estimates.
Schedule Estimates		
Traceable	N/A	CCP provided no government-developed schedule durations for the ICA team to review. The ICA team did review limited schedule data prepared by the providers.
Executable		CCP's mid-2017 first launch date of a certified system is achievable based on independent analysis assuming they receive sufficient and stable funding.

***Finding #1**: The government cost estimates for each provider used an acceptable and consistent estimating methodology across each of the estimates and applied the estimating methodology correctly. The majority of the estimates are documented to a level of detail where any qualified cost estimator could reproduce them from scratch if provided the same datasets. A consistent estimating methodology was used across the three government cost estimates which is a best practice.*

***Recommendation #1:** CCP's cost estimating team should continue its best practice of using the same estimating methodology across the providers while continuing to research new ways to more accurately predict costs. This research may result in new estimating methodologies. Where these new methodologies result in significant cost changes from the initial estimate, CCP should perform a root-cause analysis to determine the cause of the delta. When appropriate, CCP should extend the new estimating methodologies across all three estimates to ensure consistency.*

The majority of the estimates included sensitivity and risk/uncertainty analysis. A top-level cross-check based on NASA historical cost growth data was included for each provider estimate. As a result, differences between the providers' cost estimates are due to differences in technical solutions, not the choice of estimating methodology. In instances where estimating methodologies vary, it is because CCP incorporated new research resulting in a more accurate estimating methodology.

***Finding #2:** The government cost estimates use the appropriate estimating methodology (analogy, parametric, build-up, or extrapolation from actuals), and are of the appropriate level of detail, for a program in the design phase. The majority of the estimates are parametric or analogy. Typically detailed engineering build-up estimates are not as common at this stage of the life cycle.*

***Recommendation #2:** CCP's cost estimating team should develop an approach to validate their estimates using the extrapolation from actuals methodology to improve the accuracy and credibility of the estimates.*

CCP's acquisition strategy required the CCP estimating team to develop alternative analyses to quantify the cost savings expected from commercial efficiencies in order to inform their estimate. The CCP cost estimating team cross-checked their estimates against partner-provided expenditure data from Space Act Agreements to address lack of provider cost data.

Finding #3: *The CCP cost estimating team developed high quality cost estimates despite encountering two challenges. Estimating "new ways of doing business" encouraged by CCP's alternative acquisition strategy has very limited historical precedence within NASA. Additionally, lack of cost data due to limited provider financial reporting requirements reduced the CCP estimating team's ability to validate their cost estimates against high-fidelity sunk-cost data.*

Recommendation #3*: CCP's cost estimating team should continue their practice of incorporating new data from the providers or other sources into their estimates in a timely manner. CCP should continue to evaluate the cost benefit tradeoff of acquiring additional data from the providers to improve the accuracy and credibility of the existing cost estimates over time.*

CCP used NAFCOM to develop their hardware development costs. NAFCOM is an acceptable parametric model because a previous study of Falcon 9 costs, as well as CCP's own internal calibration study successfully demonstrated NAFCOM is capable of estimating commercial development efforts when the model is calibrated correctly. CCP incorporated lessons learned from previous studies and its own studies into their cost estimate, which demonstrates their ability to apply past best practices to new, complex initiatives. Traditionally, NAFCOM is used during the design phase. Since many of the providers' subsystems are already in development, CCP needed to reinterpret NAFCOM's new design parameter to account for completed work in addition to heritage. The ICA team finds this interpretation to be valid.

Finding #4: *NAFCOM is an acceptable model for estimating hardware development costs. There is limited information to inform how best to calibrate NAFCOM or adjust estimates extracted from NAFCOM to account for "new ways of doing business".*

Recommendation #4: *CCP's cost estimating team should perform additional research with respect to the best ways to account for "new ways of doing business" in their cost estimates.*

Additional NAFCOM research that should be accomplished by CCP can be separated into three areas. The first area involves comparing provider sunk-cost data to phased NAFCOM estimates to identify potential cost deltas. A root cause analysis should be performed to validate the program's cost and schedule assumptions where expenditures deviate from the phased NAFCOM estimates. The second area encompasses researching commercial and government space vehicle development costs. Where data exists, CCP should compare similar government and commercial development efforts to determine the range of cost savings typically experienced by non-government space development programs. This could be applied using an outputs-based risk methodology to a NAFCOM estimate developed using traditional government inputs to provide a cross-check to the current estimate. The third area is developing higher-fidelity estimates within parametric estimating tools such as SEER or Price as more detailed information becomes available from the providers and comparing those outputs to the current NAFCOM estimates for each provider.

Finding #5: *The government's cost estimates for each provider are based on optimistic ground rules and assumptions resulting in cost estimates that are optimistic. Cost risk and uncertainty analysis conducted on the cost estimates excludes, or underestimates, the potential risk and uncertainty impact of these assumptions when bounding the estimates.*

Recommendation #5*: CCP's cost estimating team should work to bound cost and schedule risks associated with these assumptions and incorporate them into each of the three provider estimates.*

Three examples of this optimism include: 1) optimistic provider mass assumptions, 2) no major subsystem redesign due to closure of certification gaps from the cost estimate, and 3) a historically low systems integration cost estimate. The ICA team conducted independent analysis of these three areas and discuss these findings in the following section.

Independent Analyses

Three independent analyses related to NAFCOM mass assumptions, provider design compliance, and system integration cost were conducted by the ICA team that supports the notion that CCP's cost estimates are optimistic. Mass was the primary cost driver in the NAFCOM model used to develop the majority (on average, 74%) of each of the three cost estimates. The CCP NAFCOM model inputs assumed the provider's do not consume their stated mass plus allowance which was an optimistic assumption. Cost risk and uncertainty created by this mass assumption is underestimated. The estimates assume no major subsystem redesigns are required due to certification gaps for each provider. The ICA team conducted a review of each provider's technical solution and found that significant design changes are likely - making this assumption best-case. Cost risk and uncertainty created by this assumption are not included in the estimates. Finally, system integration costs for each provider were estimated at a percentage achieved by few completed NASA programs and represent an optimistic scenario. Cost risk and uncertainty created by this assumption are not included in the estimates.

NAFCOM Mass Assumptions

In the NAFCOM estimates, mass is the key cost driver. Because of this, the ICA team performed an analysis to assess whether the mass assumptions in the provider estimates were realistic. The CCP team used provider technical data along with the American Institute of Aeronautics and Astronautics (AIAA) standards to calculate the NAFCOM mass inputs.[5] The CCP team used a similar methodology for inputting mass to NAFCOM for all three providers.

Mass growth allowance is defined by AIAA as "the predicted change to the basic mass of an item based on an assessment of the design maturity and fabrication status of the item, and an estimate of the in-scope design changes that may still occur."[6] Using this definition provided by AIAA, mass growth allowance fits more as a "Most Likely" mass scenario, rather than a "High" value, or "worst case"

[5] AIAA Standard S-120-2006 , Mass Properties Control for Space Systems
[6] AIAA Standard S-120-2006 , Mass Properties Control for Space Systems

scenario. Essentially AIAA defines mass growth allowance as a mass contingency that is intended to be used over time.

By using the AIAA contingency mass or the "Mass plus Contingency"/"Mass plus MGA" as the "High" value, CCP's mass assumptions are too narrow. Since mass growth allowance is expected to be used, it should represent the most likely input into each provider's NAFCOM model.

NASA Agency guidance does not prescribe specific treatment of mass growth in cost estimates. In the absence of a specific NASA protocol to follow regarding mass, it is useful to examine the Air Force Cost Analysis Agency (AFCAA) analysis and resulting practices.[7] AFCAA found that space vehicle mass grows an average of 33% from authority to proceed (ATP) to launch. Figure 4 demonstrates that as the project matures, the base mass is expected to continue to grow until the final phase where it reaches the mass plus contingency level.

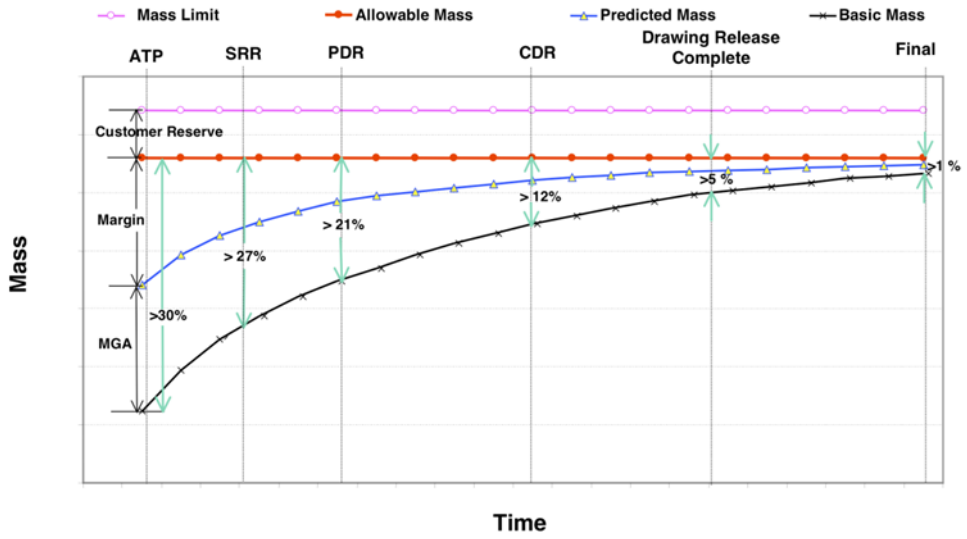

Figure 4: NAFCOM Weight Analysis

AFCAA research uncovered that historically, mass growth from ATP to launch has averaged 33% (39% in programs started after 1990), Figure 5 details this research. Although each CCiCap provider is well past ATP, these statistics still provide a high-level cross-check against which mass growth projections can be sanity checked.

[7] AF Cost Risk and Uncertainty Handbook (AFCCA). 2007.

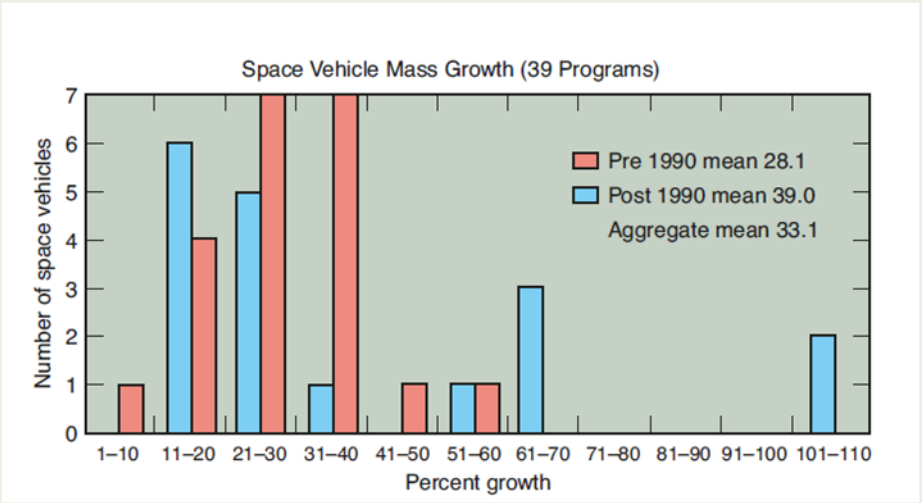

Figure 5: Space Vehicle Mass Growth

Provider Design Compliance

The CCP team's cost estimates assume no major redesign of subsystems due to certification gaps. Because redesign can significantly impact cost, the ICA team examined this assumption. A group of technical subject matter experts (SME) reviewed the technical documentation from commercial provider design reviews in order to assess the possibility of major subsystem redesign. The technical team reviewed the same dataset that the CCP cost estimation team used to inform its estimates. The documentation was from select milestones from the CCDev 2 and CCiCap[8] development activity.[9]

The SME reviewers looked for items of technical risk that could affect program cost, schedule or achievement of technical requirements. The SMEs also assessed the levels of technical maturity of provider subsystem design concepts. These SME assessments were compared with the CCP NAFCOM New Technology scores for each provider estimate model in order to assess the level of technical risk associated with technology readiness level (TRL) maturity on the designs.

The SME team looked for and identified gaps in provider system design compliance with the baselined CCP requirements and specifications suite. Particular attention was paid to compliance gaps that will likely drive provider design changes with measurable impact on cost and schedule if suitable requirements relief cannot be negotiated between the providers, CCP, ISS program and NASA Technical Authorities.

Costs arising from major subsystem redesigns caused by requirement certification gaps were excluded from the CCP provider cost estimates and not reflected in the estimates cost risk or uncertainty scope. Based on the identified gaps and the experience of SMEs from multiple past NASA Human Spaceflight programs, the ICA team believes that these ground-ruled assumptions of no major redesigns due to certification gaps is optimistic.

[8] Sources: CCDev 2 Milestone Reviews (May 2011-February 2012) and CCiCap Milestone Reviews (August-October 2012)

[9] Assessed data considered accurate as of October 29, 2012.

CCP has achieved requirements stability to a high degree at an early stage in the program's life cycle. Achieving this baseline is notable given the challenge of gaining consensus across the breadth of internal/external stakeholder organizations including the International Space Station Program (ISSP) as well as the engineering, safety and mission assurance (S&MA), and health and medical technical authorities. Many of these requirements are decomposed directly from the Agency's Human Rating Certification Procedural Requirements. Others are founded in past NASA program experience and have strong stakeholder adherence to their importance to safety of flight. As part of the Certification Products Contract Phase, NASA will review provider certification plans V&V plans, hazard analyses and proposed alternate standards. CCP leadership will consider requirements variances and specification/standards tailoring to resolve design non-conformances. Deviations from the established baseline will require acceptance from agency stakeholders. Given the uncertainty of acceptance of these deviations, the underlying assumption regarding no major subsystem redesign is optimistic.

ICA technical subject matter experts independently identified a set of candidate risk items based on their review of provider design data in their areas of expertise. These independently developed risks were collected into a candidate risk register. The experts then reviewed their candidate risks to identify impact ranges for cost and/or schedule on a low, most-likely, high scale. These inputs were all collected and a team review was held in conjunction with the cost estimating review team to determine which of these discrete risks were truly uncovered in the three government estimates. A large number of the candidate risks were seen to be bracketed within the NAFCOM systems integration portion of the estimates. Additionally, a number of the risks were translated into adjustments to the New Technology/Design section of the NAFCOM estimates.

New Design scores were seen to require some adjustments based on technical SME review. These adjustments in most cases reflected increases in the most likely and high scores for the NAFCOM distributions. The adjustments in many cases reflect the technical team's assessment of design changes needed for compliance with NASA key specifications. The technical team was mostly in agreement with government estimate scoring for the levels of technical maturity of provider subsystems.

Systems Integration Cost Analysis

Since systems integration (SI) costs are estimated as a percentage of the sum of systems integration plus hardware DDT&E[10] and are a significant cost driver, the ICA team examined the percentage value used in the estimates. NAFCOM defines system integration costs as the total of integration, assembly and checkout, system test operation, ground support equipment, system engineering and integration (SE&I), program management, and launch and orbital operations support. CCP expanded on NAFCOM's definition of systems integration costs by adding program support and vehicle integration to allow the cost team to cross-check against historical cost data that also included these additional items.

Systems integration is the portion of the estimate that heavily reflects "new ways of doing business." However, there are limited analogies that capture commercial ways of doing business. CCP identified three programs, Pegasus, SpaceHab, and Atlas V, and estimated systems integration costs at a similar

[10] SI% = SI/(SI+HW DDT&E)

percentage. The ICA team reviewed these analogies and due to increased human rating requirements required by CCP and the complexity of integration, the ICA team does not feel that these are appropriate analogies to the CCP program. Atlas V was an unmanned launch vehicle, SpaceHab was an ECLS system shielded within the shuttle's cargo bay, and Pegasus failed, or was only partially successful, 5 of its first 14 flights, a metric unacceptable for human spaceflight.

The ICA team sought to broaden the comparative dataset. In order for the ICA team to assess the percent of systems integration costs relative to additional programs, we used the NAFCOM SI definition and identified the corresponding NAFCOM SI percentages from the CCP estimate.

Once the ICA team determined the CCP estimates SI percent using the NAFCOM definition, the team collected additional SI cost data from over 100 NASA programs in the NAFCOM database. Costs at the levels of the CCP estimates have only been achieved by a few programs analyzed by the ICA team. Because the CCP estimated SI costs are a very low percentage relative to other NASA programs, the ICA team considers the estimated SI costs to be an optimistic assumption.

The ICA team selected three NASA missions, Apollo CSM, Gemini, and Shuttle Orbiter, to cross check against the CCP SI cost estimates. Figure 6 charts the SI cost as a percentage of DDT&E for the three CCP providers, the three missions the ICA team selected and the NASA average.

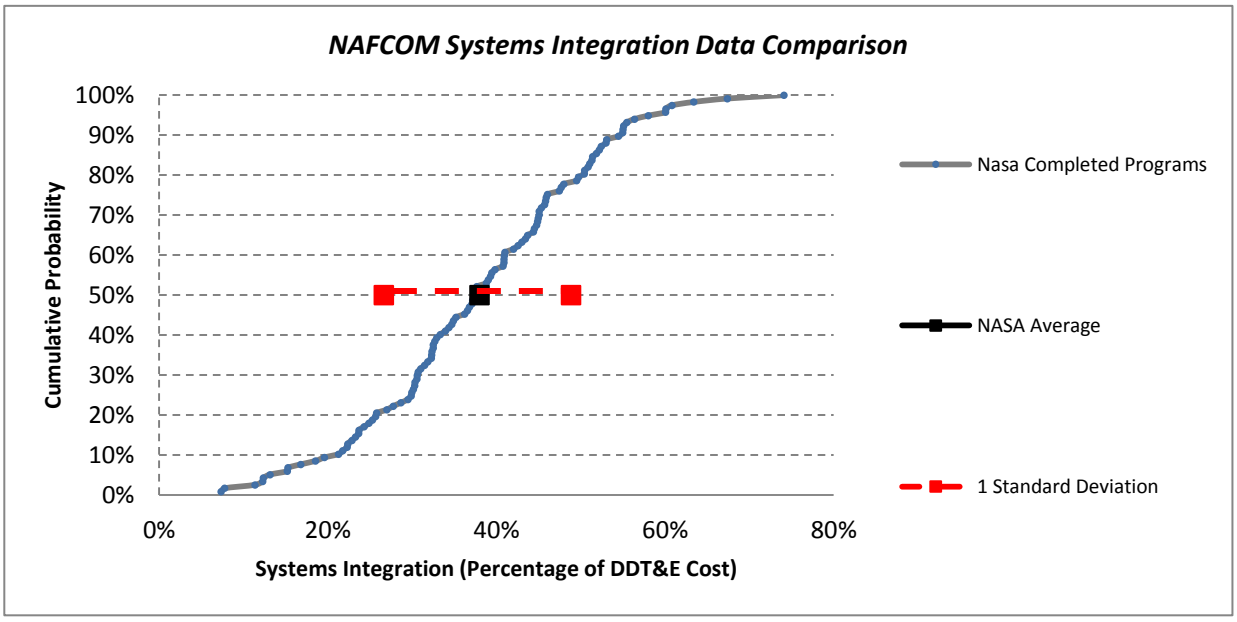

Figure 6: NAFCOM Systems Integration Data Comparison

As hardware development costs increase, SI costs increase as well because SI costs are directly related to DDT&E costs. This creates additional uncertainty to SI cost estimates. The CCP team did not include risk or uncertainty in their SI cost estimates, and therefore these estimates do not account for the potential for SI costs to increase due to uncertainty around the percentage or due to uncertainty in DDT&E costs.

The ICA team considers the CCP's estimate of SI costs to be an optimistic assumption because SI costs are estimated at a very low percentage relative to other NASA programs, including analogous programs such as Apollo CSM, Gemini, and Shuttle Orbiter. While the ICA team acknowledges that CCP's reasoning that "commercial ways of doing business" will result in greater efficiency and therefore a lower SI cost than the previous NASA crewed missions and lower costs than the NASA average, the CCP estimate is still considered optimistic. The inherent complexities of the CCP mission and the risks involved in crewed space flight introduce significant risk factors to overall hardware DDT&E costs, which, in turn directly increase SI cost. The ICA team believes that a more conservative estimate would use the CCP's SI cost estimate as a lowest possible value, the NASA average as a highest possible value, and a most likely value falling somewhere between the two.

Independent Duration ROM Estimate

CCP provided no government-developed schedule durations for the ICA team to review. The ICA team did review limited schedule data prepared by the providers.

Finding #6: *No government duration estimate exists for any provider. CCP is currently relying on the accuracy of the provider-defined milestones. The absence of a government duration estimate for each provider makes it difficult to ensure the government cost estimates align to a schedule and reduces CCP's ability to independently evaluate the providers' milestones and associated schedule artifacts, where available.*

Recommendation #6: *CCP should transition to a more robust parametric cost model with integrated schedule capabilities.*

There are several methods the program can use to develop these estimates. One method is to compare predicted versus actual performance for meeting CCiCap milestones. Many of the upcoming milestones for CCiCap represent the completion of technical scope and will provide some data points by which to bound schedule risk and uncertainty for each provider. Another method is to use a parametric estimating tool, preferably one with integrated schedule capabilities. Lastly, CCP can build and validate a program analysis schedule. The ICA team recognizes that CCP is not required to produce an integrated master schedule (IMS). However, a high-level analysis schedule focusing on key milestones would allow the program to independently model key integration points for each provider.

Reserve and Alternate Budget Assessment

Approach

The ICA team performed an assessment of CCP cost and schedule plans, focused on UFE, to complete development of a certified commercial transportation system. As CCP had already conducted a budget exercise linking their cost estimates to multiple funding scenarios, and the ICA team found this exercise to be valid, the decision was made to evaluate program's cost and schedule plans using a similar methodology

To validate the analysis, CCP's cost estimate was replicated in the ICA team's UFE model. Benchmarking analysis revealed that the ICA team's model was able to reproduce CCP's cost estimates, including risk analysis, within 1%. This analysis, which was independently validated by the program, ensured differences in findings and results were due to differences in assumptions, not estimating methodologies.

To evaluate UFE, additional sources of cost and schedule risk identified by the ICA team were added into the model. These risks included:

- NAFCOM Mass Assumption Optimism
- NAFCOM New Design Factors Optimism
- NAFCOM Systems Integration Optimism
- Ground Systems Cost Risk
- Provider Profit Deferral Risk

To allow the ICA team to quickly evaluate various funding scenarios, the UFE model was adapted to allow analysts to adjust the following inputs:

- Budget profile
- Provider(s) selected
- Final year of each provider's funding
- Level of provider investment
- Confidence level at which each provider is funded

Overview

To accomplish the reserve and budget alternative analysis, the ICA team needed to evaluate projected program funding and budget constraints. This included assumptions and inputs used during execution of the program's most recent budget exercise. The budget exercise performed by the program linked the government cost estimates to their program's budget plan to analyze program funding strategies consisting of single and multiple providers. A corresponding risk analysis was performed to quantify mass/new design risk, systems integration risk, the assumption in the CCP estimates that providers will not realize profit until the services contract, and discrete risks identified by the ICA technical team.

The basis for the reserve and budget alternative analysis was the projected CCP program budget. Assessment of phased independent risk-adjusted cost estimate to program budget plus UFE determined the adequacy of funding to support program strategy

Finding #7: *CCP performed a budget exercise linking the government cost estimates to their program's budget plan to analyze program funding strategies consisting of single and multiple providers, displaying a best practice of incorporating cost estimates into budget planning exercises.*

Recommendation #7: *CCP should continue to link cost estimates and available budget to program funding analysis and keep their budgetary exercise up-to-date by incorporating latest estimating, budgetary, and risk data as they become available.*

Analysis

The budget assessment was comprised of a quantitative risk analysis and review of the budget exercise conducted by CCP, which led to assessment of program UFE. The risk analysis quantified cost and schedule impacts of each risk identified. The assessment of CCP's budget exercise evaluated program assumptions and incorporated risk analysis input. Results of this assessment provided the foundations for the UFE assessment.

The ICA team utilized NAFCOM to replicate CCP's cost estimate with modified risk assumptions. The New Design scoring of systems in CCP's NAFCOM files based on subject matter expert reviews of CCiCap & CCDev 2 milestone products were adjusted. These adjustments in most cases reflected increases in the most likely and high scores for the NAFCOM distributions. The adjustments in many cases reflect the technical team's assessment of design changes needed for compliance with NASA key specifications. The technical team was mostly in agreement with government estimate scoring for the levels of technical maturity of provider subsystems.

Finding #8: *The ICA team analyzed the optimistic ground rules and assumptions (see Finding #5) identified additional risk to government cost estimates. Risks identified in analysis include mass/new design NAFCOM input optimism, systems integration cost estimate optimism, the assumption in CCP estimates that providers will defer profit from development contracts until the services contract, and discrete risks identified by ICA technical team.*

Recommendation #8: *CCP should develop program positions on these risks and take action to incorporate them into their program strategy. Where non-monetary actions cannot mitigate the risk, the program should ensure funds or UFE exist to cover the potential impact of these assumptions.*

These risks were not accounted for in the government estimate, supporting the finding that the government estimates are optimistic. By taking a more conservative approach to risk, the ICA team hopes to provide the government with key areas to focus on in order to better control possible cost risk.

Based on the risk analysis, CCP should develop program positions on these risks and take action to incorporate them into their program strategy; accounting for them in their cost estimates/budget exercise by including them in either the government cost estimates or UFE analysis. CCP should incorporate these additional risks into its holistic approach to managing cost and schedule growth. This is accomplished through a combination of methods such as lowering the impact of risk through mitigation strategies (e.g., avoidance actions such as requirements relief), planning for risk occurrence by incorporating it into the government cost estimates, protecting against the risk by budgeting UFE to cover its potential impact, and providing business incentives for providers to minimize cost growth and encourage provider investment to pay for cost growth during P2CC.

Budget Exercise Assessment

CCP team performed a budget exercise linking the government cost estimates to the FY 2013 President's budget request to analyze program funding strategies consisting of single and multiple providers. The budget exercise assessment included current and constrained funding levels. The latest cost estimates were incorporated into the budget planning exercise based on the program funding analysis.

Finding #9: *CCP continues to address budget challenges impacting crew transportation service acquisition. CCP monitors its budget relative to cost through the program's budget plan process and conducts rigorous budget exercises to inform the program's acquisition strategy.*

Recommendation #9: *CCP should continue to incorporate their financial and affordability constraints into the program's acquisition strategy to enhance the likelihood that at least one provider is successful.*

UFE Assessment

UFE Exercise Analysis Approach

One of the key goals of the UFE exercise was to include risk assumptions within the cost model given CCP budgetary constraints. A corresponding risk analysis was performed to quantify mass/new design risk, systems integration risk, the assumption in the CCP estimates that providers will not realize profit until the services contract, and discrete risks identified by the ICA technical team.

Finding #10: *UFE levels established in PMR are not based on a quantified analysis of program risk and uncertainty.*

Recommendation #10: *CCP should use an accepted cost-risk analysis methodology to analyze and inform UFE levels in future budget planning. Analysis should account for uncertainty in government cost estimates and program risks that could impact government cost estimates. This analysis should be time-phased to ensure UFE is available when needed.*

The CCP team should be proactive in identifying key cost drivers to mitigate various cost risks as it pertains to UFE. In line with CCP's strategic vision, cost-risk analysis will improve future budget planning and the efficient allocation of resources.

UFE Exercise Model Benchmarking

The ICA team replicated the CCP cost estimates in the ICA Budget Exercise Model to have a model that allowed for greater functionality than the CCP model. The ICA model was built with various toggles so that sensitivity analyses can be performed real-time. The ICA model inputs include the budget profile, provider selection, final year of each provider's funding, percent of provider investment, and the confidence level funding for each provider. The ICA team first benchmarked the ICA Budget Exercise Model against CCP cost estimates to ensure consistency with CCP analysis. This benchmarking showed that the ICA budget exercise model was able to reproduce CCP's cost estimate within a two percent margin. This model was provided to the CCP team, and the CCP team agreed that the ICA Budget Exercise model was able to reproduce the CCP estimate results accurately.

ICA Risk Adjusted Estimate vs. CCP Government Estimate

After benchmarking the ICA Budget Exercise Model and confirming it accurately replicates the CCP government estimate, the ICA team then added in the quantified risks that were previously identified. It is important to note that with the ICA budget benchmarked, the differences between the ICA risk adjusted model and the CCP government estimate are differences in risk assumptions, not differences in the actual modeling.

The ICA team added the quantified risks identified (mass/new design, systems integration, provider profit, and discrete risks) as triangular distributions. Once the quantified risks were added to the model, Monte Carlo simulation was used to run 10,000 simulations of the model. Results were assessed at the 50^{th} percentile to remain consistent with CCP estimating methodology. The resulting values are representative of the CCP government estimates plus the additional risk identified and quantified by the ICA team. CCP has already committed a level of funding to each provider and these funding commitments are also included in the model. The ICA risk adjusted model results in higher estimates and supports the finding that the government estimates are optimistic. Further budget analysis indicates that projected annual appropriations do not align with the phased cost estimates that the CPs will have to address.

Finding #11: *In both the CCP and ICA Budget Exercises, projected annual appropriations levels are below yearly phased cost estimates. Providers will be expected to fund the gap in their P2CC plans.*

Recommendation #11: *CCP should communicate their anticipated year-to-year budget constraints to the providers to allow them to adequately plan for this constraint in their P2CC proposals.*

Provider actions, which could impact cost to CCP and ISS, include holding schedule and accepting or financing a negative cash flow for several years up front, slipping schedule, shifting work content to out-years, and either incorporating the cost impact into their bid or funding it through additional provider investment, and choosing not to bid on P2CC. Current annual appropriations levels will leave providers cash-flow challenged if schedule is to be held and any additional redirection of funds during P2CC will likely lead to a slip in schedule. Deviations from annual CCP investment funding amounts assumed by the providers in their P2CC proposals could lead to schedule slips and cost growth in the services contracts.

III. Improving Cost Estimating Practices Recommendations

Based on insights gained as a result of partner-focused and program-focused assessments, recommendations regarding data needs and estimating approaches for cost and price analysis to support future NASA service acquisition and analysis are provided.

Data Need Recommendations

Cost and schedule estimates are only as good as the fidelity of information used to support them. The ICA team reviewed all the data provided as part of the partner-focused and program-focused assessments. It was determined that there are potential high priority data elements that the program could benefit from having improved fidelity on for future cost and schedule estimates.

These elements include:

- American National Standards Institute (ANSI) Compliant Earned Value Management (EVM) System
- Selective Cost Reporting
- Integrated Schedule
- Risk Register Data

Cost Estimating Practices Recommendations

The ICA team evaluated additional estimating approaches or methods to enhance the equality of future cost and price estimates. The findings and recommendations in this section pertain to the UFE/reserve generation, mass assumptions, and NAFCOM.

UFE/Reserve Generation

Finding: NASA's Joint Confidence Level policy formally links cost estimates to program budgets but never stipulates how budgets should be divided between allocated funds and reserves. This has resulted in a culture of rules-of-thumb and "gold-standards" for setting program reserve levels. Although NASA's existing JCL policy addresses programs' total budget, it does not address the phasing of reserves from year to year. This can leave programs underfunded in years with greater risk and overfunded in years with less.

Recommendation: NASA should provide guidance for how programs can use results from a JCL analysis to divide their budget between allocated funds and program reserves. This guidance should also include recommendations on how programs should allocate reserves by year based on the risk and uncertainty levels associated with those years. In general programs should allocate funds at no higher than a 50% confidence level to mitigate effects caused by the self-fulfilling prophecy when programs use all of their allocated funds in any given year regardless of need. All other funds required to meet JCL policy should be placed into program reserves.

Mass Assumptions

Finding: NASA has no guidance for estimating risk-adjusted mass growth for parametric cost estimating models. At worst this could result in a systemic underestimation of mass. At best this could result in an uneven application of mass-growth assumptions across program cost estimates.

Recommendation: NASA should undertake the following actions to better estimate mass across programs. This should include collecting NASA historical mass data, where it exists, from CADRe documents and analyze mass growth between program milestones – comparing to AIAA standards[11] interviewing other agencies with space acquisition programs to understand how they estimate mass, and developing an agency-level guidance document for developing mass assumptions for parametric cost estimates.

NAFCOM

Finding: CCP has made the decision to augment their NAFCOM estimates with the ACE-IT model in order to address current limitations with the tool.

Recommendation: The ICA team concurs with this proposed next step and recommends that NASA improve NAFCOM through a series of actions. NASA should allow input distributions other than triangular. Most times historical data is used to develop a distribution that distribution will have a fit other than triangular. Forcing NAFCOM inputs to be entered as triangular distributions has limited the use of NAFCOM outside of NASA and results in less-accurate cost estimates. Additionally, NASA should allow uncertainty to be entered on systems integration costs and global parameters. A leading source of cost risk on CCP, and most other programs, was systems integration costs. Because NAFCOM does not allow uncertainty to be placed on this (or several other) key parameters, CCP could not model this risk within the tool.

[11] AIAA. (2006). AIAA Standard S-120-2006, Mass Properties Control for Space Systems

IV. Conclusion

The CCP cost estimating team should be commended for execution of program cost estimate development. The team adhered to GAO and NASA quality standards despite having to overcome challenges unique to developing CCP's cost estimates. The difficulties of estimating the "new ways of doing business", encouraged by CCP's alternative acquisition strategy and very limited historical precedence, created an enormous challenge. The challenge was made greater by the lack of provider cost data to validate the estimates due to the limited reporting requirements. Regardless, the government cost estimates for each provider are considered high quality. Though, due to a series of optimistic ground rules and assumptions, the estimates should be considered optimistic.

The high quality designation of the cost estimates are evidenced by general adherence to GAO and NASA cost estimating best practices and correctly using an acceptable estimating methodology. The estimates are also documented to a level of detail where any qualified cost estimator could reproduce the estimate from scratch if provided the same datasets. CCP should maintain the same estimating methodology best practices across providers in the future. CCP should also continue to evaluate the cost benefit tradeoff of acquiring additional data to improve the accuracy and credibility of the existing cost estimates over time. CCP's cost estimating team should perform additional research with respect to the best ways to account for "new ways of doing business" in their cost estimates.

The estimates are considered optimistic due to a series of optimistic ground rules and assumptions introduced in the CCP cost estimates. These assumptions include that no providers use up their mass growth allowance during DDT&E, no major design changes occur due to certification gaps, and savings in systems integration costs due to "commercial ways of doing business" will be realized. CCP's cost estimating team should work to bound cost and schedule risks associated with these assumptions and incorporate them into each of the three provider estimates.

CCP monitors its budget relative to cost through the program's budget plan process and conducts rigorous budget exercises to inform the program's acquisition strategy. CCP should continue to incorporate their financial and affordability constraints into the program's acquisition strategy to enhance the chance that at least one provider is successful. CCP should also enhance integrated acquisition, budgeting, and other planning with ISS in order to manage cost, schedule, and technical risk.

The ICA team believes that the recommendations contained within in this report and its appendices provide NASA an actionable framework to improve the accuracy and credibility of estimates required to ensure the financial success of NASA's new commercial space transportation service acquisition.

References

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V. Appendices

Appendix A: BOE Evaluation Criterion

Appendix B: Acronyms

Appendix C: ICA Team Biographies

Appendix A: BOE Evaluation Criterion

The foundation for the cost estimating methodology utilized in this ICA was based upon the Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management Framework as illustrated in Figure 7[12].

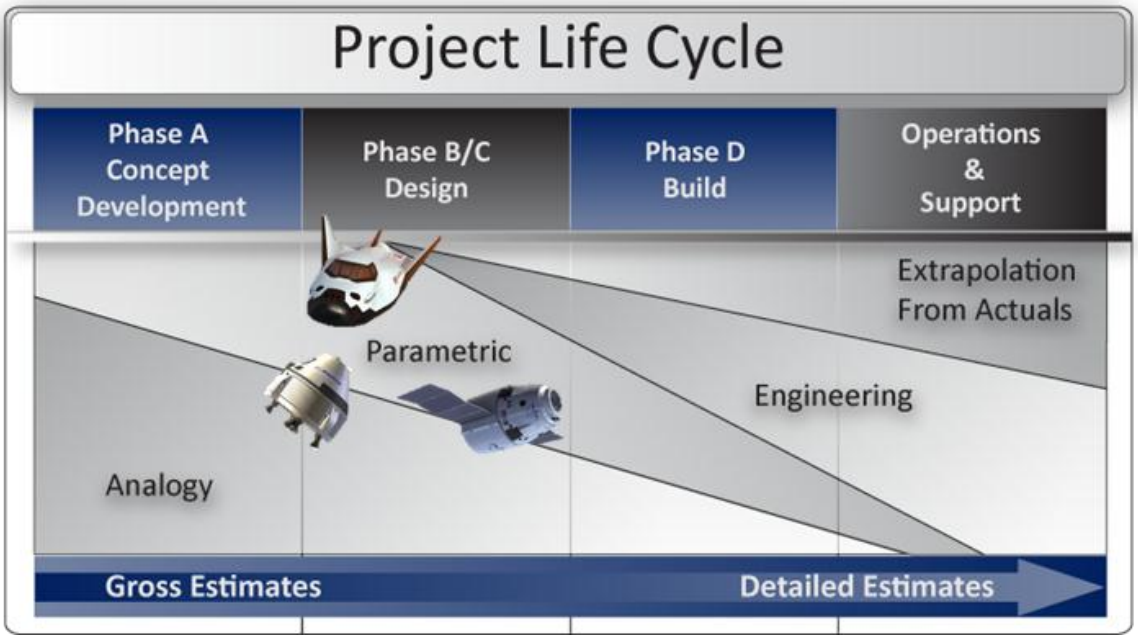


Figure 7: Project Life Cycle

This methodology utilizes four techniques for estimating cost throughout the program lifecycle:

- Analogy - Compares a new or proposed system with one analogous (i.e., similar) system, that was typically acquired in the recent past, for which there is accurate cost and technical data. There must be a reasonable correlation between the proposed and "historical" system
- Parametric - Uses regression analysis of a database of two or more similar systems to develop cost estimating relationships (CERs) which estimate cost based on one or more system performance or design characteristics (e.g., speed, range, weight, thrust)
- Engineering - Implements a detailed build-up of labor, material and overhead costs determined after a firm design is established and minimal design changes are expected to occur
- Actuals - Extrapolates current program costs in order to estimate system cost

[12] Defense Acquisition University Chart] Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management Framework chart (v5.2); Defense Acquisition University (DAU), 2008 as reproduced in the Society of Cost Estimating and Analysis (SCEA) Cost Estimating Body of Knowledge (CEBoK), Module 2

BOE Rating Criteria

The rating system used in this ICA was defined such that each estimate was evaluated on a green-yellow-red scale based on its quality and its adherence to best estimating practices as described in the GAO's Cost Estimating & Assessment and the Society for Cost Estimating/Analysis' (SCEA) Cost Estimating Body of Knowledge (CEBoK). Table 3 describes the BOE rating criteria.

Table 3: BOE Rating Criteria

BOE Cost Rating Criteria		
Green	**Yellow**	**Red**
- A green BOE is substantively well documented such that a reviewer can clearly understand and ascertain how the estimate was developed. For instance, hours in the BOE match cited actuals from an analogous program, including an explanation of why the analogous program as chose; or they were developed using a CER with the supporting data included in the case of parametric estimates. - Additionally, factors (complexity, efficiency, etc.) applied to analogous program actuals are justified using other actual. - Material dollars use quotes included in the BOE.	- A **yellow** BOE is reasonably well documented in the manner described above, but the estimate contains small (<10%) unjustified adjustment factors.	- A **red** BOE is poorly documented, not documented, or not traceable to appropriate engineering judgment, parametrics, or historical actuals. Alternately, a BOE can be red even if well-documented and based on reasonable, cited historical actuals but the estimate contains a large (>10%) unjustified or unexplained adjustment factor.

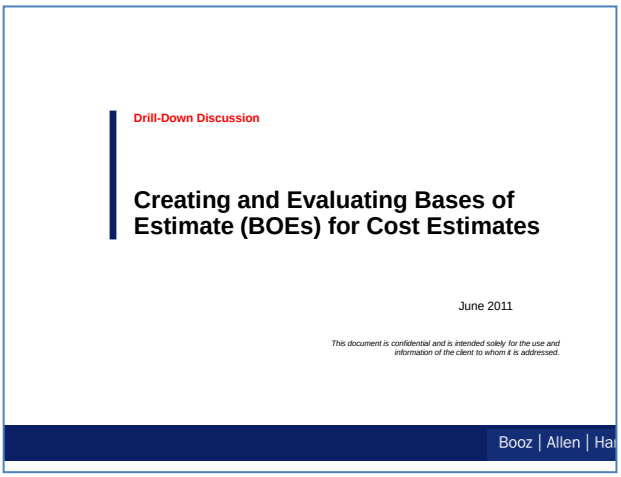
In this rating standard, Green-Yellow-Red acts as a surrogate for cost and schedule risk that exists entirely based on the maturity of the documentation.

In general, to achieve a green rating the BOE needed to fit all the criteria for a green rating as well as all of the items on the checklist associated with the estimating methodology used. BOEs based on historical data but with small, unjustified, factors received a yellow rating. BOEs based solely on engineering judgment, or those using historical data yet with large, unjustified, adjustment factors receive a red rating.

The following pages overview an expanded discussion on the evaluation of BOEs within a cost estimate:

What is a BOE?

A comprehensive, detailed explanation of the cost of a specific component of an overall cost estimate



Why is a BOE important?

Evaluations of cost/schedule estimates consider "credibility" of the cost; inadequate or inaccurate BOEs can lead to poor scoring on cost factors or an adjustment to the estimated cost

The cost estimate forms the basis for the program plan; shortcomings in the cost estimate create problems in delivery

What makes a good BOE?

Provides a complete and understandable description of the cost (or schedule); level of effort (LOE), rates, factors and assumptions

Clearly incorporates teammates & sub-contractors

Represents of overall cost/schedule strategy and program management strategy

Sufficient details to allow an independent party to arrive at the same cost/schedule; Traceable

Common BOE Errors

Common errors as identified by the Society of Cost Estimating and Analysis (SCEA)

- No basis whatsoever (or none evident)
- Adjustments with no basis (or basis not explained)
- Subs with no BOEs
- Cherry picking
- Missing elements
- BOEs out of sync with technical volume
- Two BOEs each claiming (or thinking) that the other BOE covers a cost
    - Or, less often, two BOEs claiming the same cost
- Standards errors (e.g., MH/year, POP)
- Travel or material quantities unjustified
- Facility costs/choices unjustified
- Basing the estimate on another estimate
- Learning curve errors

BOE Checklist by Estimating Methodology

Based on the estimating methodology, use the following guidelines when writing a BOE.[13]

Parametric

- Provide the specific historical data point(s) used, the type and source of the historical data, any adjustments made to the historical data and the supporting rationale for them
- Include the equation used to develop the estimate as well as the associated statistics (p-values, standard error, etc.)

Analogy

- Similar to the parametric approach, provide the historical program used and any adjustments made to the historical data

Standard Cost Models (PRICE, SEER, COCOMO, etc.)

- Identify the model and vendor
- Provide a copy of the input parameters and the rationale for why they were chosen
- Provide an explicit mapping of the cost model outputs to the cost estimate

Engineering Judgment

- Identify the individuals who contributed to the estimate and their qualifications
- Identify similar projects for which this work has been performed and how they are similar to the project being estimated
- If there are similar projects, everything should be done to pull actuals from those projects
- Cross-checking the estimate with actuals adds credibility, even if only performed at a top level

Company Standard Bidding System

- Provide details of methodology and reference any government certifications (for example, a DCMA Memorandum of Agreement)

Commercial Price (generally for the BOM)

- Include source, date of quote and any discounts (quantity or otherwise)
- Remember that quantity discounts may not come to pass if scope is reduced

[13] Society of Cost Estimating & Analysis Cost Estimating Body of Knowledge (CEBoK) Module 14: Contracts & Pricing

Appendix B: Acronyms

AFCAA	Air Force Cost Analysis Agency
AIAA	American Institute of Aeronautics and Astronautics
ANSI	American National Standards Institute
ATP	Authority To Proceed
BOE	Basis of Estimate
BOM	Bill of Materials
CCP	Commercial Crew Program
CDR	Critical Design Review
CEH	Cost Estimating Handbook
CER	Cost Estimating Relationship
CSM	Command/Service Module
CTS	Crew Transportation System
DCMA	Defense Contract Management Agency
DDT&E	Design Development Test and Evaluation
DOD	Department of Defense
ECLS	Environmental Control and Life Support
EVM	Earned Value Management
FY	Fiscal Year
GAO	Government Accountability Office
ICA	Independent Cost Assessment
ICE	Independent Cost Estimate
IMS	Integrated Master Schedule
ISS	International Space Station
ISSP	International Space Station Program
JCL	Joint Confidence Level
JSC	Johnson Space Center
KSC	Kennedy Space Center
LOE	Level Of Effort
MDA	Missile Defense Agency
MGA	Mass Growth Allowance
NAFCOM	NASA / Air Force Cost Model
NASA	National Aeronautics and Space Administration
P2CC	Phase 2 Certification Contract
PMR	Program Managers Review
ROM	Rough Order of Magnitude
RY	Real Year
S&MA	Safety and Mission Assurance
SAA	Space Act Agreement
SCEA	Society For Cost Estimating and Analysis
SE&I	System Engineering and Integration
SI	Systems Integration
SME	Subject Matter Expert
SNC	Sierra Nevada Corporation
TRL	Technology Readiness Level
UFE	Unallocated Future Expense
WBS	Work Breakdown Structure

Appendix C: ICA Team Biographies

Core ICA Team

Team Member	Expertise
Marguerite Morrell – Task Manager	Principal with Booz Allen Hamilton. 20 years of experience in capital planning, financial and economic analysis, and cost estimating and analysis. Ms. Morrell manages a team that is focused on providing economic analysis, financial and resource management, and project controls to NASA and Air Force clients. Conducted financial and cost analyses at Logistics Management Institute as well as PepsiCo. Began career as a civil/structural engineer for Bechtel. Holds a BS in Civil Engineering from Carnegie Mellon University and an MBA in Finance from Columbia University.
Eric Druker – Task Manager / Technical Lead	Mr. Druker has seven years of space cost estimating experience across NASA, DoD and the Intelligence Community. Technical lead for Booz Allen's Decision Analytics support to NASA Headquarters and lead the first two NASA Joint Confidence Level Analyses (JCLs) s to go through the SRB process. Cited in the GAO's Cost Estimating and Assessment Guide. Named the Society of Cost Estimating/Analysis' National Cost Estimator of the year in 2009 for Technical Achievement. Recipient of a letter of commendation from NASA's Landsat Data Continuity Mission Program in 2009.
Joseph Sarage – Cost Analyst	Mr. Sarage has nine years of experience in financial management and analysis, including financial statement analysis, cost estimating, cost modeling and forecasting, budget planning and formulation, congressional budget justification, and performance management. In addition, Mr. Sarage has extensive experience in statistical analysis, including development of econometric models coupled with a strong foundation in economics and finance. Mr. Sarage holds an MBA in Finance from Johns Hopkins University, an MA in Economics from American University, and a BA in Managerial Economics from Stonehill College.
Kevin Ingoldsby – Technical Analyst	Mr. Ingoldsby has over 25 years of experience supporting NASA across a broad range of spaceflight applications while at Cape Canaveral, Florida. He was the leader of the Ground & Mission Operations Systems Integration Group for the NASA Constellation Program office from 2006-10. His experience supporting SLS precursors, such as the X-33 project and multiple Space Shuttle upgrade studies, provide him a strong basis for concept studies and technology analysis. Mr. Ingoldsby holds BS and MS degrees in Physics from Creighton University.
Dwight Lettsome – Risk Analyst	Mr. Lettsome has over 10 years of experience in the Air Force and NASA markets. He spent four years in the Air Force where he served as a research and development technician and project officer. While with Booz Allen, Mr. Lettsome has worked on numerous projects including, NASA's Constellation Program as a systems engineer and software and avionics test and verification strategic planner. He holds a BS in Mechanical Engineering and an MBA.
Mario Fountano – Schedule Analyst	Mr. Fountano is a PMP certified professional with over 13 years of consulting experience in program/project planning & controls with industry recognized expertise in scheduling and Primavera P6. Mr. Fountano serves as a functional SME for proposals and technical publications and has provided career management for Booz Allen Hamilton staff.
Ramzi Shuhaibar – Analyst	Mr. Shuhaibar is a junior cost analyst at Booz Allen. He has previous experience in fund accounting, and holds a BS in Business Administration from Northeastern University.

ICA Senior Review

Team Member	Expertise
Bill Bastedo	Extensive 25 year history with NASA supporting complex spacecraft and missions, including the Space Shuttle, International Space Station, and Constellation program. Both a civil servant and consultant at Reston/Headquarters, Kennedy Space Center, and Johnson Space Center. Experience in systems engineering support throughout all phases in a program lifecycle.
Craig Starnes	Mr. Starnes is a Vice President at Booz Allen Hamilton and has over 24 years of professional experience across all facets of program management to include: business/financial management, economic analysis, decision analytics, portfolio management and systems engineering. Previously, Mr. Starnes served as the firm's market lead across the US Army/Missile Defense Agency (MDA) Missiles and Space community.
Fred Blackburn	Decades of experience supporting the US DoD, with multiple national level security intelligence agencies. Received two Director of Central Intelligence Meritorious Unit Citation Awards, and is recognized for his expertise in cost estimation, risk analysis, earned value management, and resource management. Knowledge of satellite and launch systems associated with the security intelligence agencies.
Steve Wright	Over 25 years supporting NASA Human Space Flight in variety of engineering capacities. Designed and tested space hardware, defined and managed International Space Station configuration and assembly concepts, supported the planning for the STS-88/2A shuttle mission, and providing leadership to the Constellation Technical Services Contract.

Technical Review Team (ICA Subject Matter Experts)

Team Member	Expertise
Bruce Morris	Mr. Morris has over 27 years of experience in the employ of NASA, in several leadership positions at Marshall Space Flight Center, most recently as the manager for the Exploration and Space Systems Office in the Science and Mission Systems Directorate. He has deep experience representing NASA in joint Air Force analysis of alternatives studies.
Bob Gates	Mr. Gates has over 27 years of experience supporting the NASA Human Space Exploration projects. Currently based in Houston, Texas, Mr. Gates has managed the International Space Station Systems Analysis and Integration Team, the Traffic Modeling Tool for the European Space Agency, and participated in the evaluation of several ISS design and assembly options to support long term strategic planning, as well as many other systems engineering and analytical engineering tasks
Scott Bellamy	Mr. Bellamy has over 26 years of experience supporting the Air Force and NASA, notably as the Air Force Space Command Liaison to NASA Marshall Space Flight Center. Mr. Bellamy's extensive background in rocket propulsion provides him the experience and knowledge to act as the rocket propulsion subject-matter expert.
Gary Brown	Mr. Brown has over 28 years of experience supporting NASA and Department of Defense space programs. In his capacity as program manager for Space Launch Initiative project office at JSC and program office as MSFC, Mr. Brown has been highly involved in the architecture design and definition of the 2nd Generation Reusable Launch Vehicle. As program manager of Booz Allen's Constellation Technical Support Contract, Mr. Brown became an expert on new launch systems and their design and technical operations.
Robert Puckett	Mr. Puckett has over 22 years' experience in systems engineering, program/project management, and integrated performance analysis while working on NASA's ISSP and the Constellation Program (CxP). Prior to joining Booz Allen, Mr. Puckett managed the Vehicle Integrated Performance and Resource (VIPeR) team for the ISS prime contractor.
Wayne Thompson	Mr. Thompson has performed systems engineering and system safety engineering work on various SE&I contracts in support of DOD MILSATCOM, Air Force Space Launch Ranges and NASA human space flight programs. He has also participated in various strategic planning studies supporting NASA, Air Force and NRO space launch programs. Prior to his work at Booz Allen, Mr. Thompson served in the Air Force in various assignments (squadron, wing, air division, specified command, joint command and joint staff) in missile and space operations.
Lisa Gievers Davies	Ms. Gievers Davies has 18+ years of supporting the Air Force procuring air and space programs both as an Air Force officer and as a Booz Allen employee. She has worked both the program management and engineering aspects of programs and is currently supporting the Air Force program office responsible for launching National Security Space satellites.

Programmatic Review Team

Team Member	Expertise
Ed Crooks	Mr. Crooks is a Vice President at Booz Allen and leads the firm's activities in infrastructure project finance and innovative delivery at the McLean, Virginia office. For five years prior to coming to Booz Allen, Mr. Crooks was a Managing Director in KPMG's Infrastructure Advisory practice. He has worked on high speed rail programs, highway projects in Texas, Florida, and Virginia, and water projects in Florida and New York. He was KPMG's lead on the advisory team preparing Amtrak's business and financial plan for the Northeast Corridor high speed rail program.
Mike Thomas	A Senior Vice President at Booz Allen Hamilton, Mike Thomas supports the broad security initiatives of the firm. His key areas of expertise include systems development and technology, and he has worked closely with the intelligence community. Prior to joining Booz Allen in 2010, Mr. Thomas was president of the Security Product Line at Lockheed Martin's IS&GS organization, where he provided knowledge solutions capabilities, intelligence mission management, and processed and disseminated intelligence data for enhanced national and tactical decision making.
Jim Manchisi	A Senior Vice President at Booz Allen Hamilton, Jim Manchisi leads the firm's Systems Engineering and Integration (SE&I) business in the international market. Prior to joining Booz Allen in the spring of 2006, Mr. Manchisi served as President of the Space Systems Division of ITT Industries, President of the Commercial and Government Systems Division of Eastman Kodak, and General Manager of the Barnes Division of EDO Corporation.
Trey Obering	Trey Obering is a Booz Allen Hamilton Senior Vice President based in McLean, Virginia. An expert in acquisition and program management, he works with aerospace clients in the Air Force Material Command, Air Force Space Command, and NASA markets. Prior to joining Booz Allen, he led a comprehensive review of the National Reconnaissance Office for the Director, National Intelligence, which provided a new charter for that organization. Mr. Obering retired from the US Air Force as a Lieutenant General with more than 35 years of experience in space and defense systems development, integration, and operations.
Tom Dauber	Mr. Dauber has over 19 years of experience in support to the US Government, with national level security agencies. Managed cost estimating and analysis in support of the acquisition process for security agency clients, with extensive background providing economic and cost analysis.